A Web Based Version of OzClim for Exploring Climate Change Impacts and Risks in the Australian Region

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1. EXTENDED ABSTRACT

OzClim ver.3.0 is a web application family, including both a web service application and web applications, written for the Microsoft™ .NET framework which delivers information about regional climate change for Australia and associated risk and uncertainty.

The three major components of the system are:

(a) An online data store which contains three databases. The first is patterns of change extracted from a variety of global climate models provided for the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007) and available from Program for Climate Model Diagnosis and Intercomparison at http://www-pcmdi.llnl.gov/. The global climate model data is held in a separate data store which can be processed off line or may be processed on demand by OzClim Web Service Application. The second database is baseline observations from the Bureau of Meteorology, and the third is a set of global warming time-series.

(b) OzClim Web Service Application and its cache provide a rich set of routines accessible via either Simple Object Access Protocol or .NET remoting.

(c) The following web applications. **OzClim Web**, a Web Application written in Java, running on Apache Tomcat under Solaris™, and which provides a web presentation layer as Java Server Pages. **OzClim Research** GUI which is under current development is a .NET Web Application written in Delphi and queries the OzClim Web Service using .NET remoting. **OzClim Console** is an ASP.NET console application which provides a simple command line interface.

Design goals are:

(a) provide climate change projections based on the Intergovernmental Panel on Climate Change Fourth Assessment Report climate data;

(b) access for various users from a single data source. e.g. general public, climate students, and researchers;

(c) support multiple user interfaces from a single server interface. e.g. web pages, web enabled applications and a command line interface for use in a scripting environment; and

(d) provide climate projections in a format suitable for use in integrated assessment models and process based models.

The web application, OzClim Web, is intended to provide:

(a) increased accessibility to climate change projections for Australia, through a user-friendly web tool;

(b) a user-friendly tool to explain and generate projections for non-climate scientists;

(c) advanced functionality for technical practitioners; and

(d) combination of high resolution observations with interpolations from global climate models to give high horizontal resolution projections (25 kmx25km) over Australia, at 5 years intervals in the 21st century, for selected emission scenarios and global climate models.

By selecting different combinations of data from OzClim's databases and creating multiple climate projections, the user can explore the uncertainty of climate change Preston and Jones (Jones 2000; Jones et al. 2001; Preston 2007) suggest three layers of uncertainty associated with climate change: the uncertainty of emissions, of climate sensitivity and of regional patterns. The data available to OzClim ver.3.0 assist the user to address the three layers of uncertainty.

This paper will present the architecture underpinning OzClim ver.3.0, provide details of the databases, and discusses the process of generating climate projections. The final section of the paper suggests how OzClim ver.3.0 can be used to explore the three layers of uncertainty.

2. INTRODUCTION

There is a growing need to include climate change information in decision making and planning processes. Climate change data is required in forms suitable for processing in spreadsheets or GIS systems, as well as high quality graphics. Additionally Integrated Assessment Models (IAMs) have been developed to incorporate climate change impacts into assessments. These tend to be both problem and sector based, usually requiring regional climate change information to be considered. (Goodess et al. 2003).

OzClim ver.3.0 is a web service server and application family written for the Microsoft™ .NET framework which delivers information about regional climate change and associated risk and uncertainty. The main purposes of the tool are to (a) provide possible future regional climate projections across Australia, using a pattern scaling method (Mitchell et al. 1999; Mitchell 2003; Whetton et al. 2005) applied to output from global climate models (GCMs) and (b) to apply those projections to various impact models as required.

Primary goals of this version are to:

- Provide projections based on GCM data computed for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4).
- Support multiple classes of user from a single data source. e.g. general public, climate students, consultants and researchers.
- Support multiple user interfaces from a single server interface. e.g. web pages, web enabled applications, legacy PC applications and a command line interface for use in a scripting environment.
- Support hybrid applications using multiple servers. e.g. we have a research tool which references both OzClim data via one interface and observed daily station data from another.
- Support integrated assessment models (IAMs) and process based models (PBMs).
- Export data in standard formats. e.g. NetCDF, CSV, Arcview GIS.

Data is served by a web service application on a secure web server and is accessed by several web applications which may reside on separate machines. The web pages for a web browser are application served from a separate web server and display maps generated by the web service application. (See Figure 1)

3. ARCHITECTURE OF OZCLIM

OzClim ver.3.0 is written in Delphi for .NET as a web service application and a set of web applications, together with a CGI web interface written in Java.

As shown in Figure 1, the components are:

1. A data store which contains output from GCM runs as provided by Program for Climate Model Diagnosis and Intercomparison (PCMDI). This data can be processed off line or may be processed on demand by OzClim Web Service Application.
2. OzClim Web Service Application and its caches. This provides a rich set of routines accessible via either Simple Object Access Protocol (SOAP) or .NET remoting, and programming interfaces which can provide both data and meta-data.
3. Web applications. At present three applications are available, a CGI web application, a .NET web application, and a Windows console application.

The web applications are:

OzClim Web is a Web Application written in Java, running on Apache Tomcat under Solaris™, and which provides a web presentation layer as Java Server Pages (JSP). The OzClim Web Service Application using SOAP, produces spatial maps of climate change on a regional scale and also provide area-averaged data. The configuration database runs on Oracle. This is the publicly available version intended for general dissemination of climate change information.

OzClim Research GUI that is under current development. It is a .NET Web Application written in Delphi and queries the OzClim Web Service using .NET remoting to obtain configuration data, and to provide maps of climate projections, and export data in a variety of formats. This provides a platform for rapid development of impact models and greater flexibility.

OzClim Console is an ASP.NET console application which provides a simple command line interface to any nominated OzClim Web Service Application. This adds the capacity for scripted extraction of climate change data e.g. for incorporation into various PBMs and the production of animations.

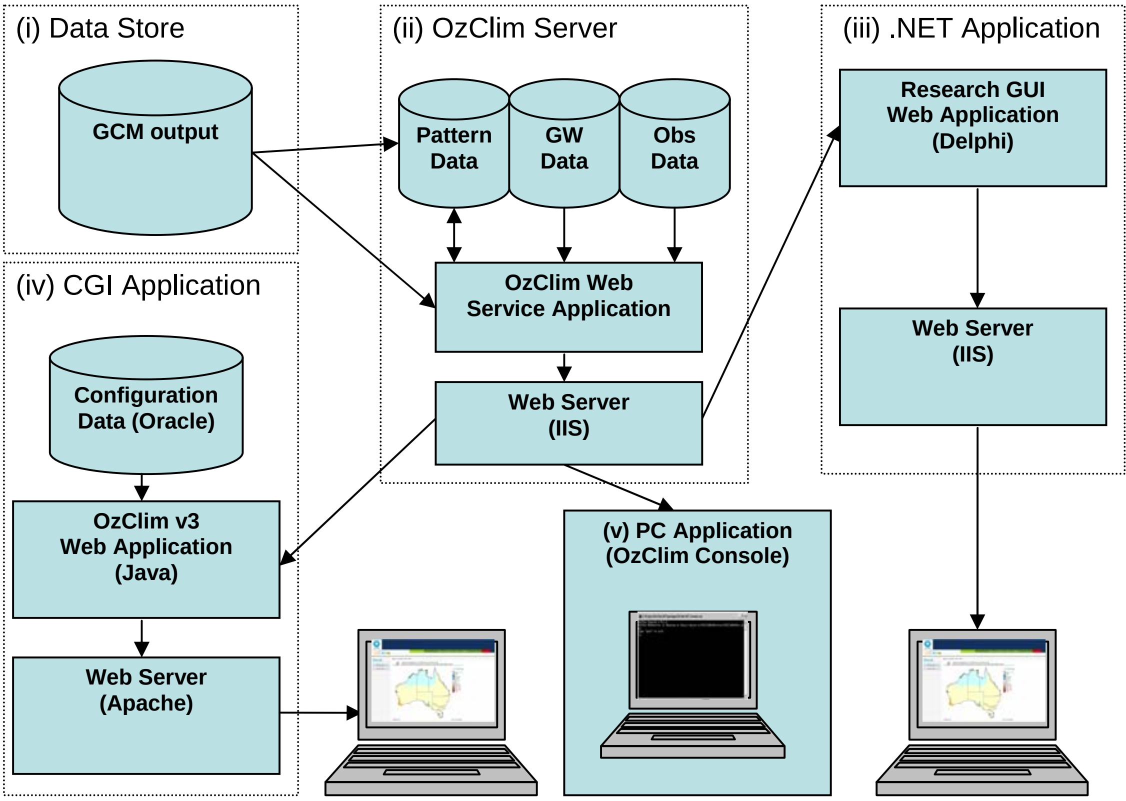

Figure 1: Components are (i) GCM output in a data store, (ii) OzClim Server comprising Web Service Application with three databases, accessed via a Web Server, and (iii…v) various applications. In (ii) the three databases are; "Pattern Data": patterns of change extracted from GCM output, "GW Data": global warming curves extracted from emission scenarios; "Obs Data": Observed base climates.

The data store is available to feed current GCM output data to OzClim web service application, and this can be done off line or on line. Currently the data store runs behind a secure firewall quite remote from the other components.

OzClim web service application requires reasonably high performance local storage and has been run from a virtualized machine behind its own firewall. It administers its own databases, caches and run-time data, and provides access to data via either SOAP or .NET remoting.

OzClim web application was developed independently and used the resources of CSIRO's IM&T team. An Oracle database was chosen for configuration data since this is a standard of the team, and itself may reside independently of the Java application which references it.

The web server which executes the OzClim web service application is Microsoft ™ IIS as is required for .NET (although there are open source solutions under development which we have not tested). At present there are no specific requirements of web servers serving the rest of the components.

PC applications require .NET framework 1.1 to be installed.

A number of advantages accrue from this general architecture. (a) The general "look and feel" of the Web application is independent of the OzClim web service application and this simplifies maintenance. (b) We have found .NET applications relatively simple to deploy. (c) It has been simple and cost effective to develop ad-hoc hybrid applications which access *multiple* web service applications and access these from different servers within a single application. (d) Applications can be quickly developed and deployed in a relatively unrestricted way with data access being controlled as required.

In practice the OzClim Web configuration database, the Java application and the Web Server which together make up OzClim Web, all reside on separate machines, and data from the data store is processed off line.

4. REGIONAL PATTERNS OF CLIMATE CHANGE

Figure 2 shows the process of creating climate projections using OzClim. The patterns of change used by the OzClim web server application to generate the climate scenarios are extracted from the GCM outputs and climate scenarios generated by OzClim are used as inputs in impact models. The following sections provide detailed information about each part.

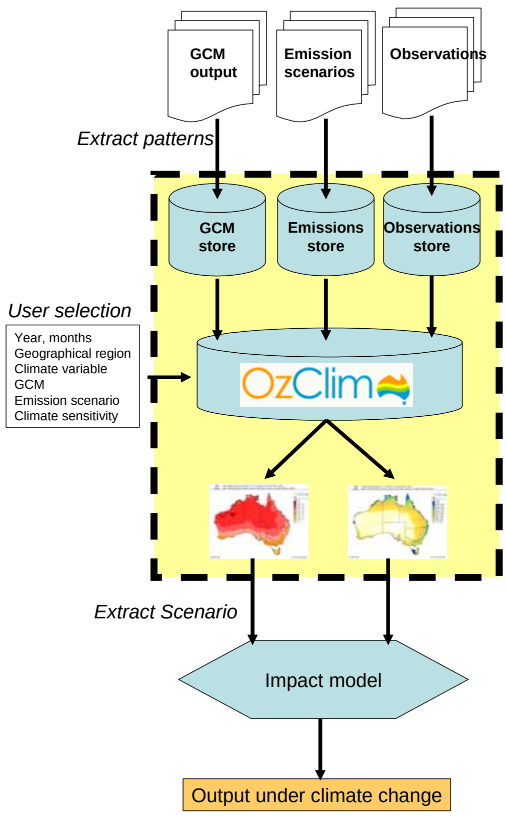

Figure 2. Flow diagram showing data storage and processes to generate climate change projections using OzClim and their applications. Source: (Page et al. 2007)

4.1. Databases

We use a period of 1975-2004 as a base period in order to center on 1990 as per (Whetton et al. 2007).

Spatial data is stored at the spatial resolution at which it was provided, and is interpolated to a common spatial resolution and grid before it is incorporated in a projection.

The **GCM database** contains patterns of change extracted from GCM output. The GCM output was obtained from PCMDI. Once the patterns have been extracted offline using a linear regression technique, the results are stored as monthly patterns of change in NetCDF files at the native spatial resolution of the GCM.

A set of time series must be extracted from the GCM output in order to generate twelve patterns of change, one for each month, for each climate variable of interest. The first time series is the annual global mean temperature for each year, denoted as W_t^*, where t is year (from first year of run to 2100). Then, for each grid-point in turn, twelve separate time series are extracted denoted as T_{tmxy}^*, one for each calendar month m (e.g. Jan 1900, Jan 1901… Jan 2100).

Once the time series have been extracted, the next step is to perform a linear regression between the annual global mean temperature and each of the twelve time series for each grid-point to generate a trend per degree of global warming for each calendar month at each grid-point.

The result is twelve spatial patterns of change. For temperature the pattern of change $\dfrac{dT_{mxy}^*}{dW^*}$ is expressed in units of degrees Celsius per degree Celsius of global warming.

For precipitation, denoted as P_{tmxy}^*, a normalization is applied to the trend in order to preserve the spatial resolution of the observed base climate, and because the precipitation predicted for the base climate of the GCM output may differ from the observed climatology.

The base climate of the GCM is defined is

$\overline{P}_{mxy}^* = \sum_{t=1975}^{2004} P_{tmxy}^* \Big/ \mathrm{count}(t)$, for each of the twelve months and each grid-point.

The monthly pattern of change for precipitation is $\left(\dfrac{dP_{mxy}^*}{dW^*} \Big/ \overline{P}_{mxy}^* \right)$ and expressed as a percentage change per degree Celsius of global warming.

GCM patterns of change, extracted from the GCMs are computed offline, and stored as monthly patterns of change in NetCDF files at the native spatial resolution of the GCM. There is one file per climate variable per GCM with twelve monthly records.

The **Global Warming database** contains twenty four time series. Each global warming time series, denoted as $\hat{W}_t$, is a combination of an individual emission scenario (one of the six SRES family emission scenarios (Nakicenovic et al. 2000) or WRE 450 or WRE 550 emission scenario (Wigley et al. 1996)) and climate sensitivity (low, medium or high), The time series have been generated using MAGICC (Wigley et al.) and stored with a temporal resolution of 5 years.

Data for the **Observations database** have been sourced from the Australian Bureau of Meteorology and are monthly climatology for the thirty years 1975 to 2004 created as part of the Australian Water Availability Project (Jones 2006). They are stored as twelve gridded monthly records in NetCDF format with one variable to a file. The spatial resolution of these is generally 0.05 degree.

4.2. Generating climate projections

Nine parameters are required from the user for OzClim to generate a climate projection for a specified year. They are: the region of interest, the desired spatial resolution, the year of interest, month or season, the climate variable, the emission scenario, the climate sensitivity, the regional pattern (the GCM), and whether the projection should be expressed as a change from base climate or the projection should be shown as the climate at the year selected.

Once the parameters have been selected and fed as inputs to OzClim, it interpolates the observed climatology and patterns of change as explained above, then calculates the change from base climate for temperature and precipitation as follows:

For temperature, the emission scenario, climate sensitivity and year selected by the user determine the value extracted from the global warming database. This value is multiplied by the monthly pattern of change at each grid-point for the selected GCM as expressed in equation 1.

$$\Delta\hat{T}_{tmxy} = \hat{W}_t \times \frac{dT^*_{mxy}}{dW^*}. \qquad (1)$$

For precipitation a similar calculation is made to generate a climate change projection. The pattern of change stored in the GCM database is multiplied by the global warming and then multiplied by the observed climate. (see equation 2).

$$\Delta\hat{P}_{tmxy} = \hat{W}_t \times \left(\frac{dP^*_{mxy}}{dW^*} \Big/ \overline{P}^*_{mxy} \right) \times \overline{P}_{mxy}. \qquad (2)$$

To determine the climatology at a given year in the future, the change expressed in equations (1) for temperature, and (2) for precipitation, are added to the respective observed climatology.

4.3. Impact models

Once climate projections are generated they can be used in PBMs and IAMs. (see Figure 2).

OzClim has provided three convenient export formats to enable users to import the climate projections into their models. The formats are a text format suitable for use in spreadsheet programs, a netCDF format, and the ArcGIS format.

5. ADDRESSING UNCERTAINTY USING OZCLIM

The sources of uncertainty related to anthopogenic climate change have been listed as the uncertainty of (a) future emission scenarios, (b) climate sensitivity and (c) regional patterns expressed by GCMs (Jones 2000; Jones et al. 2001; Preston 2007).

OzClim is a useful tool for exploring the uncertainty of climate change associated with uncertainties mentioned above.

The global warming database provides for the uncertainty of the future emissions and the climate sensitivity. OzClim enables the user to select from a variety of plausible future emission scenarios as determined by the IPCC (Nakicenovic et al. 2000) and Wigley et al. (Wigley et al. 1996) and one of three climate sensitivities (low, medium or high).

To address uncertainties associated with the regional response, OzClim provides patterns of change within the GCM database. The patterns of change were derived from the AR4 global climate model runs and where available, used ensemble averages to minimize internal model variability.

The user can combine the three uncertainties within OzClim to generate a series of climate projections. These climate projections can then be used in process-based models, impact models or risk assessments.

Figure 3 provides an example of the combination of the uncertainties in emission scenarios, climate sensitivity and regional response. The column contains eighteen diamonds. The orange diamonds represent a low global warming (as calculated by a low emission scenario and low climate sensitivity), the red diamonds represent a medium global warming (as calculated by a medium emission scenario and medium climate sensitivity) and the maroon diamonds represent a high global warming (as calculated by a high emission scenario and high climate sensitivity).

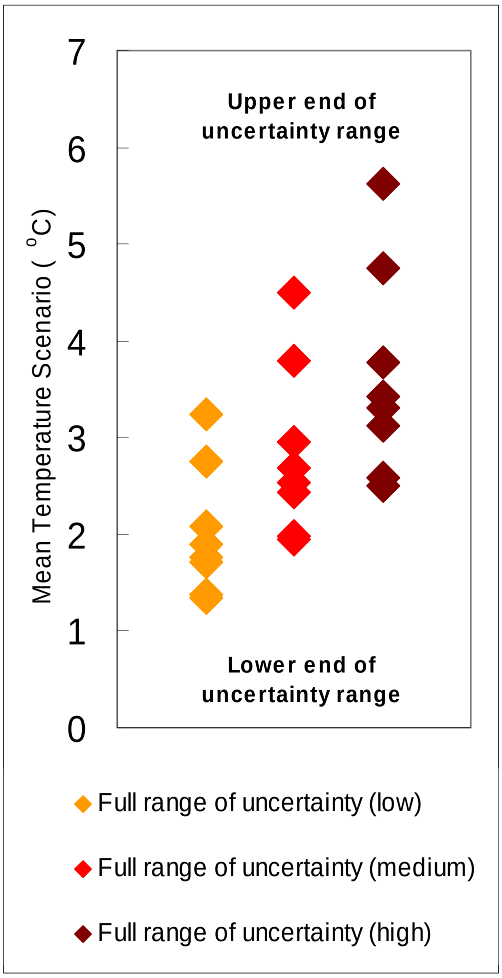

Figure 3: The range of uncertainty for a given year and location. The eighteen diamonds represent six regional patterns of change and three values of global warming (low is orange, medium is red and high is maroon).

6. CONCLUSIONS

OzClim ver.3.0 provides the spatial patterns of climate change projections within a short period of time, and provides this information as maps of change or as future climate via various interfaces including a web-browser interface and to a separate command line interface.
These projections can be output directly, fed into online impact models, or as inputs into process based models.
OzClim ver.3.0 provides access to projections based on the full set of the IPCC AR4 models available from PCMDI.
The architecture provides significant benefits, in flexibility, concurrency of data and in security.
OzClim ver.3.0 can be used to explore uncertainty surrounding climate change projections by providing rapid access to a range of possible futures. Output formats are suitable for further processing using process based models, GIS or spreadsheets.
The future directions of OzClim include the development of further integrated impact models, more tools for integrated assessments, and incorporation the latest models as they become available.

7. ACKNOWLEDGEMENTS

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